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Superconducting and Normal State Properties in the Ternary Silicide NbIrSi, TaIrSi and NbPtSi

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Abstract

The polycrystalline NbIrSi, TaIrSi and NbPtSi with an orthorhombic structure (space group *Pnma*) were synthesized by an arc-melting method. Electrical resistivity $\rho(T)$ measurement in three compounds were performed from 0.28 to 300 K. $\rho(T)$ of NbIrSi indicates typical metallic behavior with no superconducting transition down to 0.28 K. Superconducting-like behavior is observed around 0.5 K in TaIrSi, but zero resistivity cannot be observed down to 0.28 K. $\rho(T)$ of NbPtSi shows superconductivity at 1.24 K. From $\rho(T)$ in several magnetic fields, the upper critical field $\mu_0 H_{c2}(0)$ of NbPtSi is obtained to be 1.15 T.

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Keywords: NbIrSi; TaIrSi; NbPtSi; superconductivity

1. Introduction

The ternary equiatomic compounds *TrTr*'X(*Tr*, *Tr*' = transition metals; X = P, As, Si) are known as a group of superconductors with relatively high superconducting transition temperature T_c (ex. MoRuP, T_c = 15 K) [1]. These compounds crystallize in two structures; a hexagonal-Fe_2P structure and an orthorhombic-Co_2P structure. Previous reports show that *TrTr*'X compounds with the hexagonal structure generally have much higher T_c (T_c > 10 K) than

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those with an orthorhombic structure (T_c < 5 K) [2-4]. However, ternary rhodium silicide ZrRhSi [5] shows superconductivity at T_c = 10 K even in an orthorhombic structure. The report makes us motivated to discover a new high-T_c superconductor among *TrTr*'X compounds with an orthorhombic structure. Recently, we discovered a new superconductor of TiIrSi (T_c = 1.3 K) with an orthorhombic structure [6]. We expect to discover a new superconductor among Ir-based compounds. In addition, because TaPtSi is known as superconductor with T_c = 3.5 K with the orthorhombic structure [7], we also focus on Pt-based compounds to discover a new superconductor.

In this study, we performed the electrical resistivity $\rho(T)$ measurements of polycrystalline NbIrSi, TaIrSi and NbPtSi. We observed gradual decrease around 0.5 K in $\rho(T)$ of TaIrSi, and superconductivity at T_c = 1.24 K in $\rho(T)$ of NbPtSi. The upper critical field $\mu_0 H_{c2}(0)$ of NbPtSi is obtained to be 1.15 T.

2. Experimental Details

Polycrystalline samples of NbIrSi, TaIrSi and NbPtSi were synthesized by an arc-melting method. A stoichiometric composition of 1 : 1 : 1 = Nb (99.9%, grain) / Ta (99.9%, wire) : Ir (99.9%, powder) / Pt (99.9%, wire) : Si (99.999%, bulk) was melted by an arc-furnace in argon atmosphere on a water-cooled-copper hearth. The ingots were turned over and remelted several times to ensure homogeneity. The obtained samples show metallic luster.

The crystal structure of polycrystalline samples was examined by the powder X-ray diffraction (XRD) using conventional X-ray spectrometer equipped with Cu Kα radiation and a graphite monochrometer (RAD-2X, Rigaku). The intensity data were collected over a 2θ range of 10 - 90° with a step width of 0.01° at room temperature.

Temperature dependence of electrical resistivity $\rho(T)$ was measured by a standard dc-four-terminal method with a current source (Model 6221, Keithley) and a nano voltmeter (Model 2182, Keithley) from 0.28 to 300 K using a ^{3}He refrigerator (Heliox-VL, Oxford Instruments) equipped with a superconducting magnet (Oxford Instruments). Electrical leads were made by gold-wires (ϕ = 25 μm) spot-welded to a polished surface of the specimen.

3. Results and Discussion

3.1. X-ray Diffraction

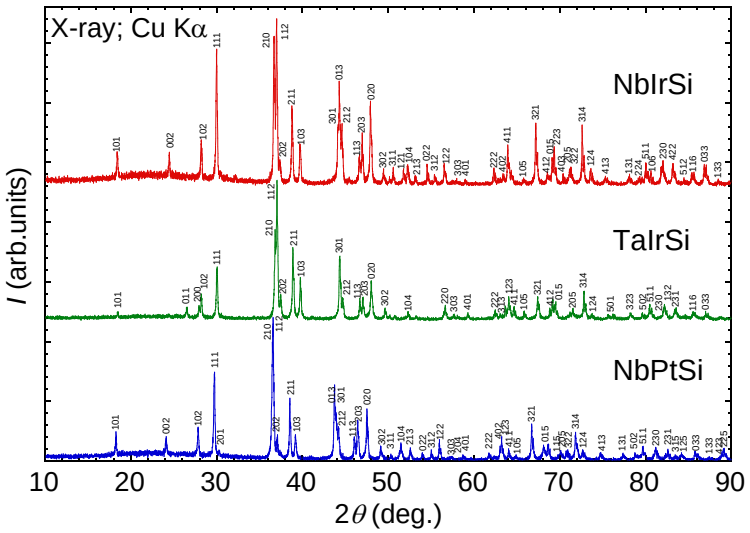

Fig. 1. Powder X-ray diffraction patterns of NbIrSi, TaIrSi and NbPtSi at room temperature.

Figure 1 shows powder-XRD patterns of the polycrystalline NbIrSi, TaIrSi and NbPtSi. The obtained patterns can be indexed as an orthorhombic structure of the space group of *Pnma*. Impurity phase is not detected in the

powder-XRD patterns. The lattice constants are evaluated to be a = 0.6408, b = 0.3794, c = 0.7273 nm for NbIrSi, a = 0.6378, b = 0.3786, c = 0.7270 nm for TaIrSi, and a = 0.6424, b = 0.3823, c = 0.7381 nm for NbPtSi, respectively. These values are in good agreement with those in the previous reports [8,9].

3.2. Electrical Resistivity

Figure 2(a) shows temperature dependence of the electrical resistivity $\rho(T)$ of NbIrSi, TaIrSi and NbPtSi. $\rho(T)$ of NbIrSi and TaIrSi indicate typical metallic behavior. Residual resistivity ρ_0 of NbIrSi, TaIrSi and NbPtSi is estimated to be 301, 94 and 82 μΩcm. Residual resistivity ratio (RRR) of NbIrSi and TaIrSi is 3.4 and 2.0. As shown in figure 2(b), superconducting transition was not observed in ρ(T) of NbIrSi down to 0.28 K. On the other hand, $\rho(T)$ of TaIrSi shows gradual decrease around 0.5 K. The decrease seems to be originated from superconducting transition. However, the achieving temperature (~ 0.28 K) is insufficient to measure zero resistivity due to the superconducting transition. In addition, superconducting transition width ΔT is relatively large ($\Delta T/2$ ~ 0.3 K), suggesting that sample quality is not high. Although impurity phase cannot be detected in the powder-XRD patterns, there is a possibility that minor impurity shows superconductivity. To reveal whether superconductivity of TaIrSi is intrinsic or not, it is necessary that measurements in lower temperature with a dilution refrigerator are performed using the high-quality sample.

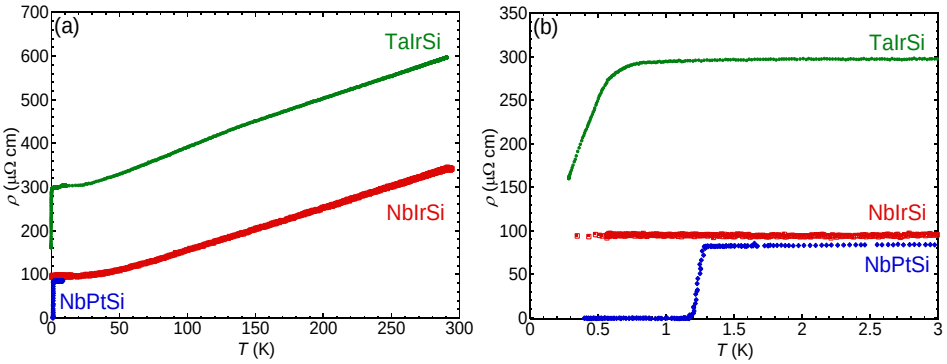

Fig. 2. (a) Temperature dependence of the electrical resistivity $\rho(T)$ of NbIrSi, TaIrSi and NbPtSi. (b) $\rho(T)$ of NbIrSi, TaIrSi and NbPtSi at lower temperature.

Superconductivity was clearly observed in $\rho(T)$ of NbPtSi. The onset of the T_c of NbPtSi was observed at 1.27 K. T_c is defined as 50% drop from ρ_0 and the superconducting transition width ΔT is taken as the temperature interval between 10% and 90% of ρ_0. These values are estimated to be T_c = 1.24 K, ΔT = 0.07 K. As shown in Figure 3(a), superconducting transition shifts lower temperature by applying magnetic fields and disappears in $\mu_0 H$ = 1.0 T above 0.3 K. The upper critical field $\mu_0 H_{c2}(T)$ of NbPtSi is plotted in Figure 3(b). The $\mu_0 H_{c2}(T)$ curve cannot be fitted to the Wertharmer-Helfand-Hohenberg (WHH) theory [10,11]. We employed the extrapolation to zero temperature using the cubic polynomial expression. $\mu_0 H_{c2}(0)$ of NbPtSi is estimated to be 1.15 T. The coherence length $\xi(0)$ defined by $\xi(0) = (\phi_0 / 2\pi H_{c2})^{1/2}$ is 16.9 nm, where ϕ_0 is flux quantum.

The enhancement of $\mu_0 H_{c2}(T)$ from the WHH prediction is attributed to several origins such as strong electron-phonon coupling, anisotropic energy gap of Fermi surface, localization effects due to impurity [12-15]. We consider that localization effects are likely in this case. Although impurity is not detected from the powder-XRD patterns, ρ_0 of NbPtSi is reasonably large as polycrystalline sample. Therefore, minor impurity and/or lattice defect exist in the polycrystalline sample, which slightly affect the superconducting state. In the present situation, because specific heat measurement of NbPtSi is not performed, superconducting state is controversial. As mentioned before, strong electron-phonon coupling and anisotropic gap are contributed to the enhancement of $\mu_0 H_{c2}(0)$ [16]. Specific heat measurement is very important to elucidate the superconducting state and the origin of the enhancement $\mu_0 H_{c2}(0)$.

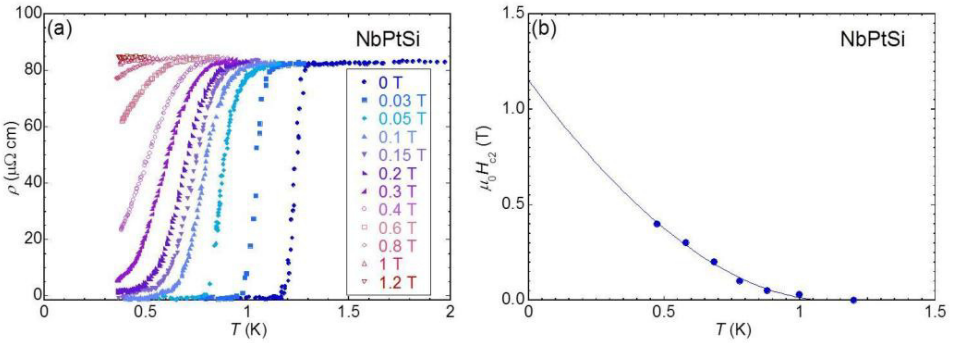

Fig. 3. (a) Temperature dependence of the electrical resistivity $\rho(T)$ of NbPtSi in several magnetic fields. (b) The upper critical field $\mu_0 H_{c2}(T)$ of NbPtSi obtained from $\rho(T)$ measurements. The solid line represents a cubic polynomial expression.

4.Conclusions

The polycrystalline NbIrSi, TaIrSi and NbPtSi with an orthorhombic structure (space group *Pnma*) were synthesized by an arc-melting method. Electrical resistivity $\rho(T)$ in three compounds were performed from 0.28 to 300 K. $\rho(T)$ of NbIrSi indicates typical metallic behavior with no superconducting transition down to 0.28 K. $\rho(T)$ of TaIrSi shows the superconducting-like behavior around 0.5 K, but zero resistivity cannot be observed down to 0.28 K. To reveal whether superconductivity of TaIrSi is intrinsic or not, it is necessary that measurements in lower temperature with a dilution refrigerator are performed. $\rho(T)$ of NbPtSi shows the superconductivity at 1.24 K. From $\rho(T)$ in several magnetic fields, the $\mu_0 H_{c2}(T)$ curve of NbPtSi cannot be fitted to the WHH theory. To estimate $\mu_0 H_{c2}(0)$, we employed the extrapolation to zero temperature using the cubic polynomial expression. $\mu_0 H_{c2}(0)$ of NbPtSi is estimated to be 1.15 T. The coherence length $\xi(0)$ of NbPtSi is calculated to be 16.9 nm. To reveal superconducting state of NbPtSi, specific heat measurement is now in progress.

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